Presentation to Contra Costa County Hazardous Materials Commission

Lithium-ion EV Batteries - Science, Challenges, Opportunities

MOHAMMED OMER - APRIL 22, 2021

Presentation Overview

Battery Science Basics

Electric Vehicle Adoption

Purpose of AB 2832 Advisory Group

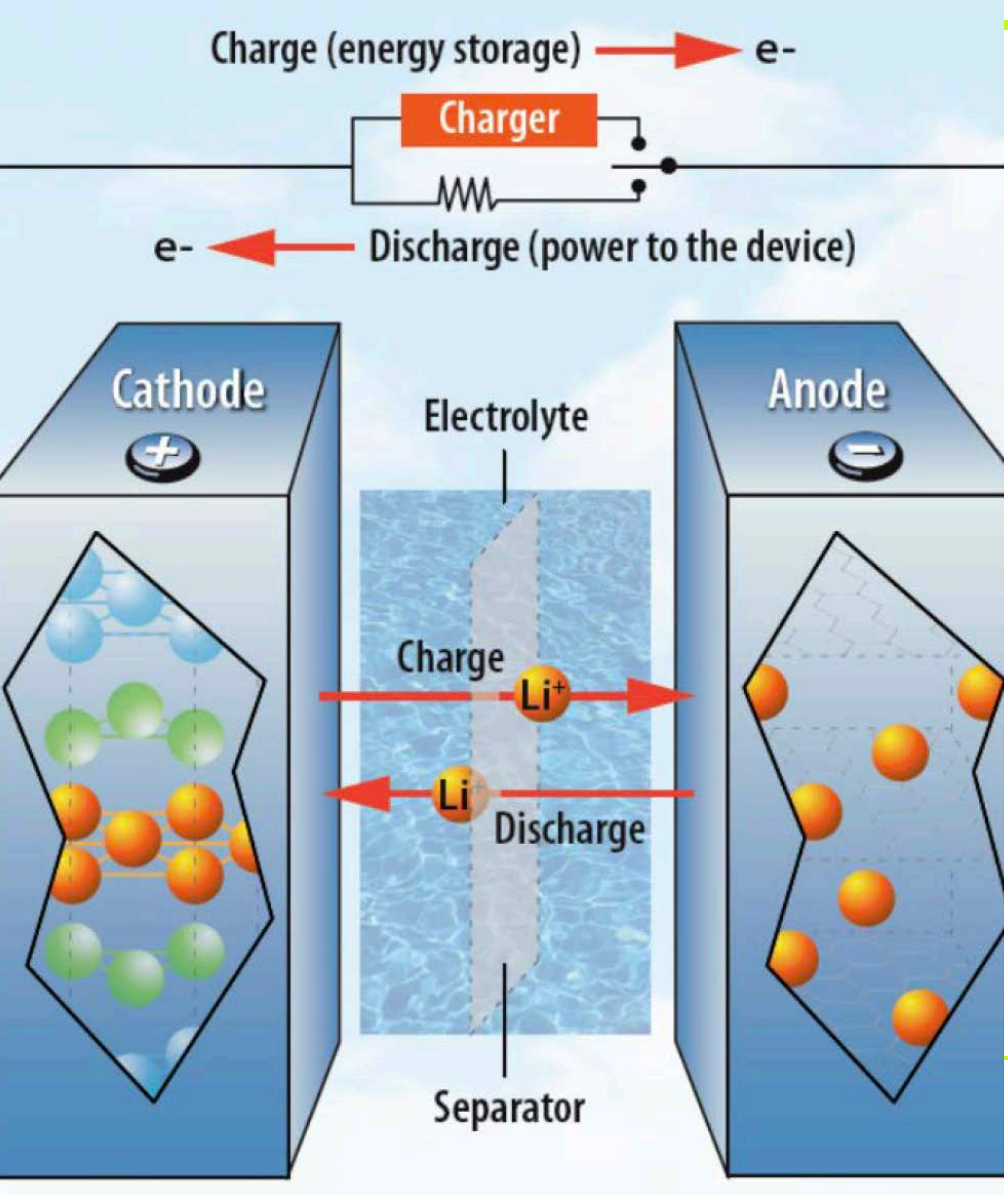
Challenges

Concepts

Get Involved

Acknowledgments

Questions

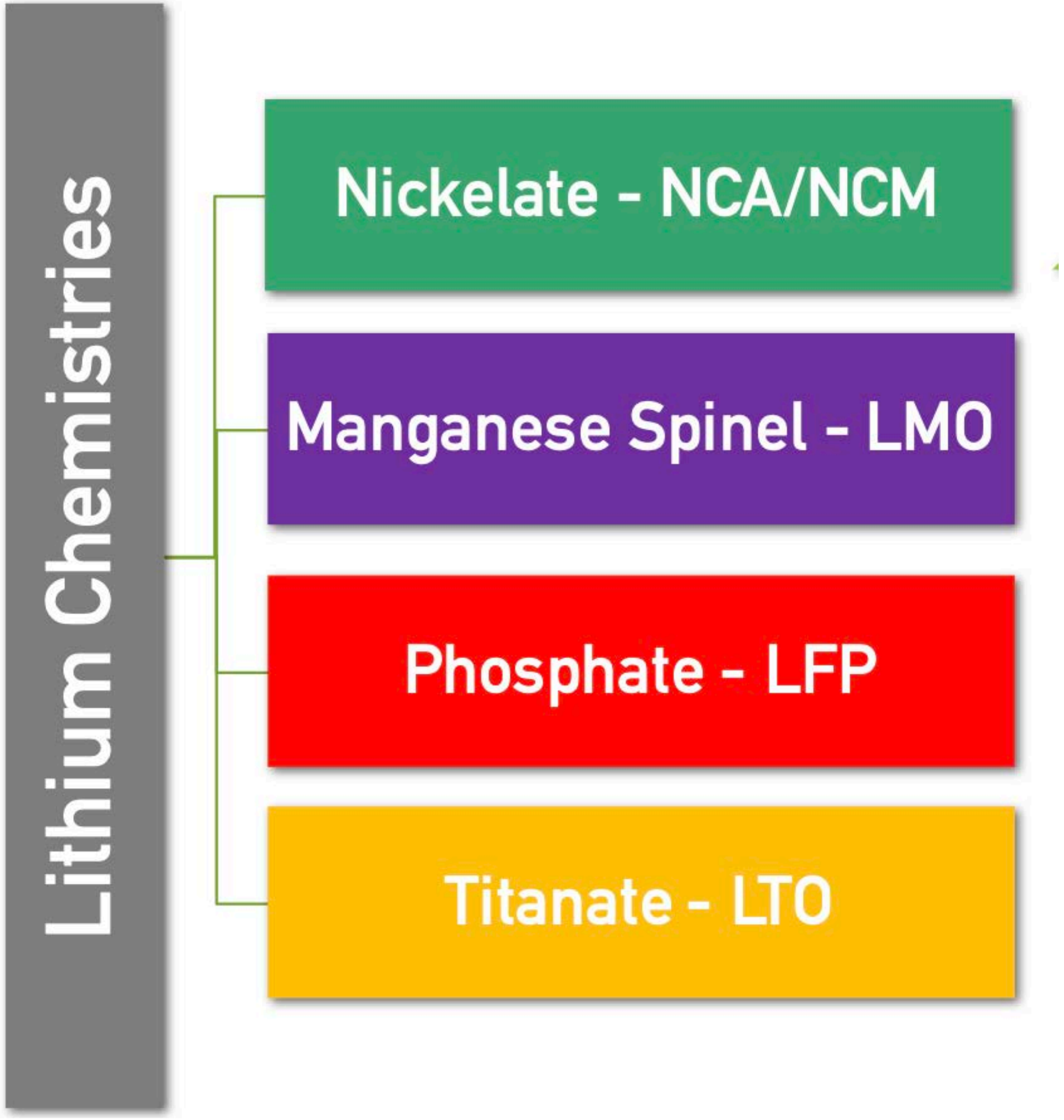


Battery Science Basics

How a battery works

- All batteries share the same basic configuration - anode, cathode, and electrolyte
- During discharge, positively charged lithium ions from the anode are emitted and pass through the electrolyte to the cathode
- Simultaneously, electrons are released from the anode - this creates the electric current which then powers the EV

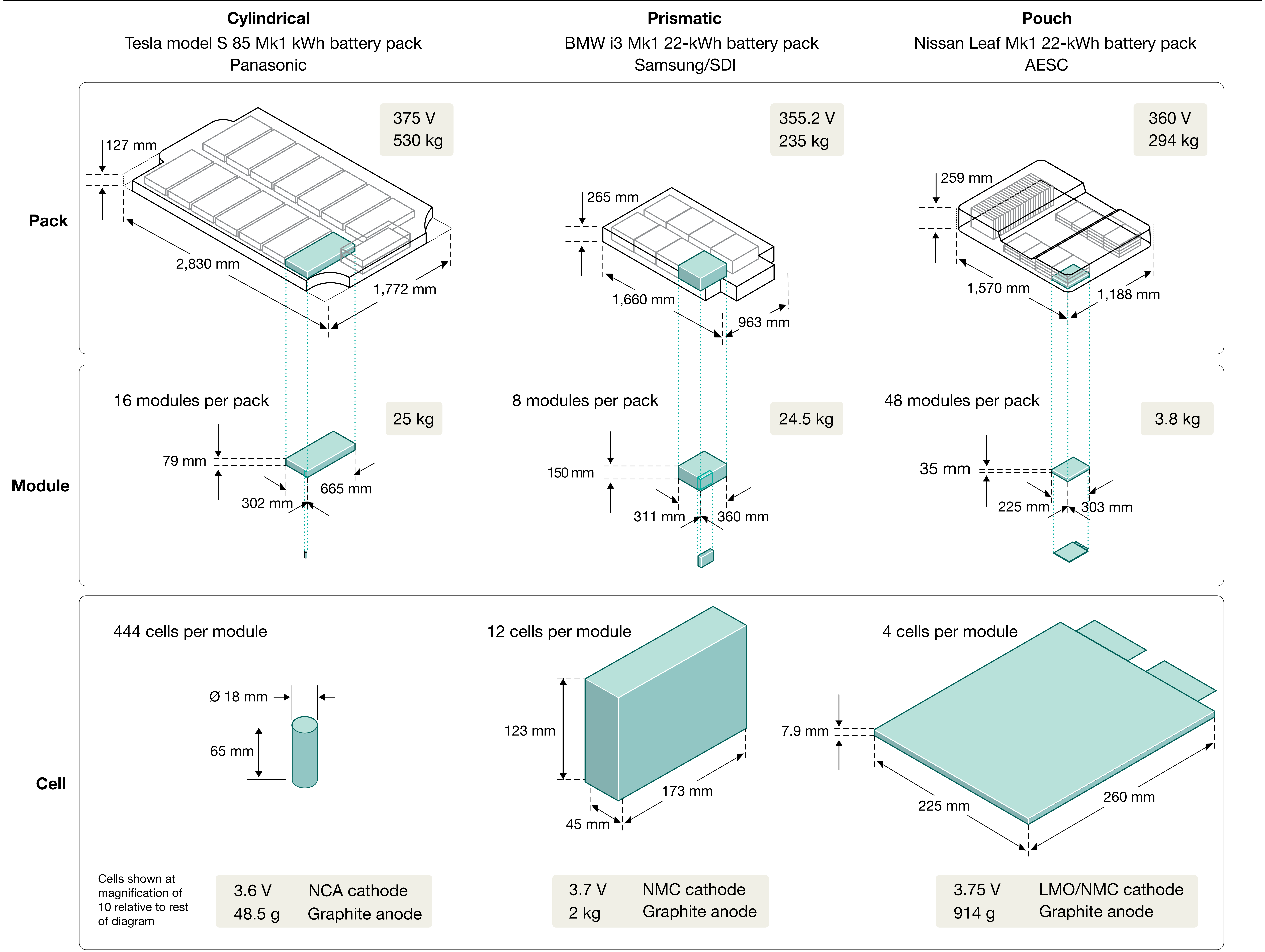
Battery Science Basics
Battery Chemistries



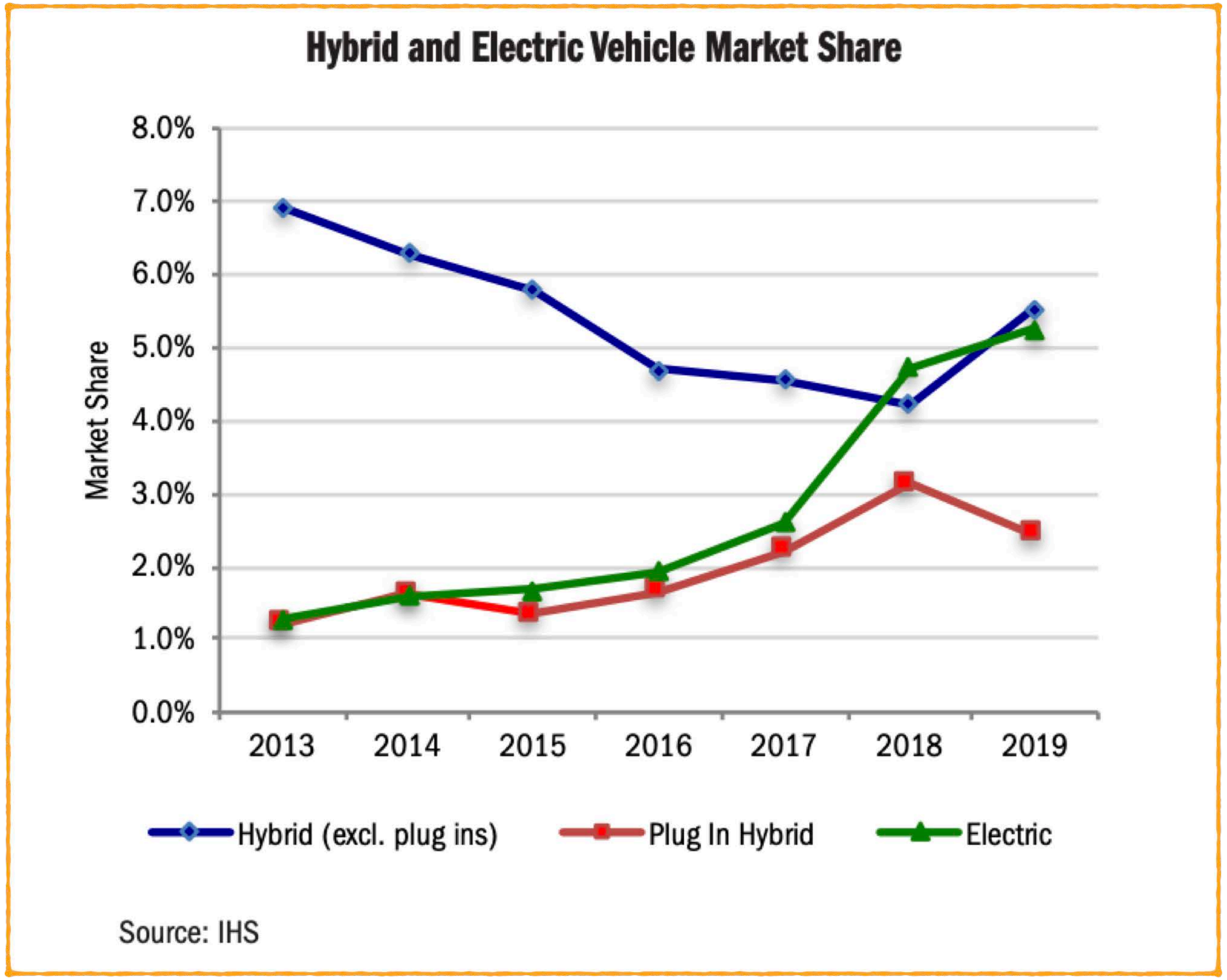
- Lithium-ion batteries differ based on their chemistries
- Anode - generally composed of carbon (graphite) powder
- Electrolyte - lithium salts and organic solvents
- Porous plastic separator
- Cathode - lithium metal oxide powder (cobalt, titanium, nickel, manganese, aluminum)

Battery Science Basics

- Lithium-ion EV batteries are formed of ***cells***, which are then arranged into ***modules***, which themselves are arranged into ***packs***
- There are a variety of different arrangements that are possible
- There is a limited similarity with lithium-ion batteries used in other consumer products
- Arrangements tend to be referred to as cylindrical, prismatic, and pouch


Cylindrical
Tesla model S 85 Mk1 kWh battery pack
Panasonic
Prismatic
BMW i3 Mk1 22-kWh battery pack
Samsung/SDI
Pouch
Nissan Leaf Mk1 22-kWh battery pack
AESC
Pack
375 V
530 kg
127 mm
2,830 mm
1,772 mm
355.2 V
235 kg
265 mm
1,660 mm
963 mm
360 V
294 kg
259 mm
1,570 mm
1,188 mm
Module
16 modules per pack
25 kg
79 mm
302 mm
665 mm
8 modules per pack
24.5 kg
150 mm
311 mm
360 mm
48 modules per pack
3.8 kg
35 mm
225 mm
303 mm
Cell
444 cells per module
Ø 18 mm
65 mm
12 cells per module
123 mm
173 mm
45 mm
4 cells per module
7.9 mm
225 mm
260 mm
Cells shown at magnification of 10 relative to rest of diagram
3.6 V
48.5 g
NCA cathode
Graphite anode
3.7 V
2 kg
NMC cathode
Graphite anode
3.75 V
914 g
LMO/NMC cathode
Graphite anode

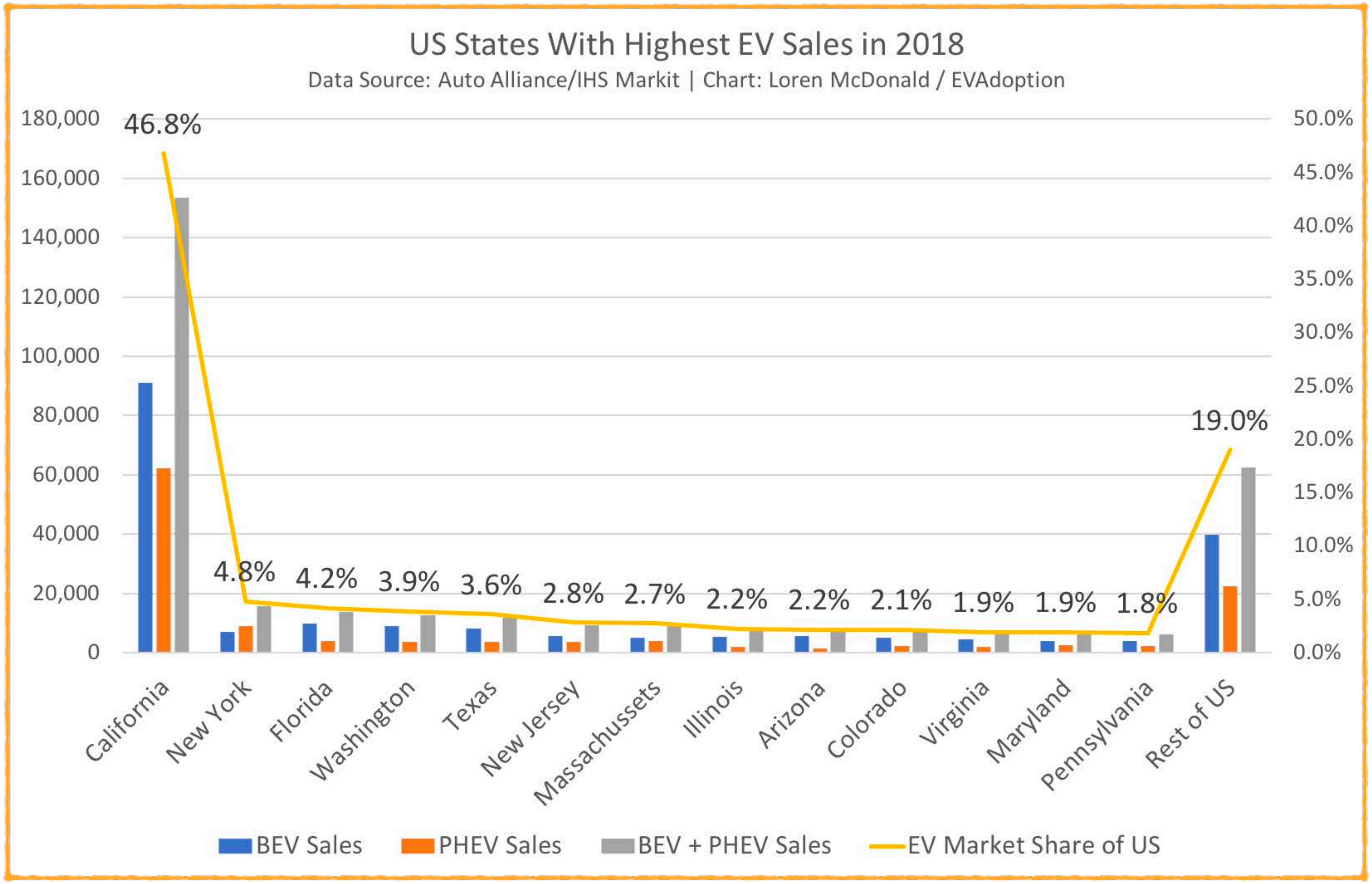
Background



- There have been numerous goals set by various levels government in California to increase the number of ZEVs statewide
- Cumulative sales of ~670,000 plug-in hybrid and all-electric vehicles (EVs) in California between 2010-2019

Credit: https://www.cncda.org/wp-content/uploads/Cal-Covering-4Q-19.pdf

California EV Market Share



Credit: https://evadoption.com/ev-market-share/ev-market-share-california/

Advisory Group History and Makeup

- In 2018, then-Assemblymember Dahle introduced Assembly Bill 2832 (AB 2832), which required the Secretary of the California Environmental Protection Agency (CalEPA) to convene the Lithium-Ion Car Battery Recycling Advisory Group (Advisory Group)
- The Advisory Group consists of representatives from CalEPA, DTSC, CalRecycle, the California Energy Commission, and various relevant industry (automobile manufacturers and recyclers) and environmental advocacy groups

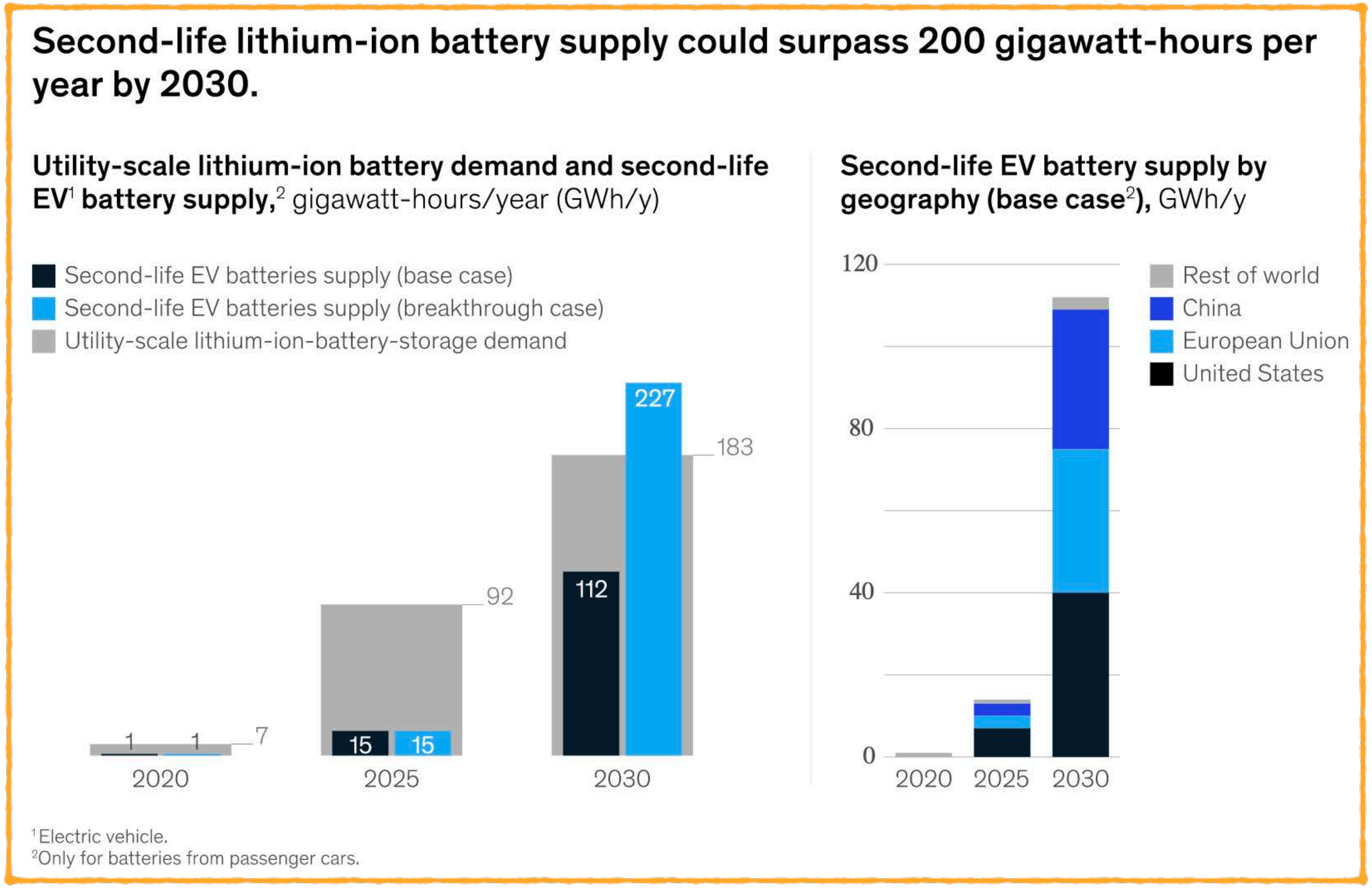
Advisory Group Goals

- The goal is “to submit policy recommendations to the Legislature aimed at ensuring that as close to 100% as possible of lithium-ion batteries in the state are reused or recycled at end-of-life in a safe and cost-effective manner” by April 1, 2022
- To accomplish this, the Advisory Group meets on a quarterly basis, at minimum, and “consult[s] with universities and research institutions that have conducted research in the area of battery recycling, with manufacturers of electric and hybrid vehicles, and with the recycling industry”
- We also meet as three separate subcommittees (Recycling, Reuse, and Logistics) on a monthly basis to perform a “deep dive” into those areas

Background

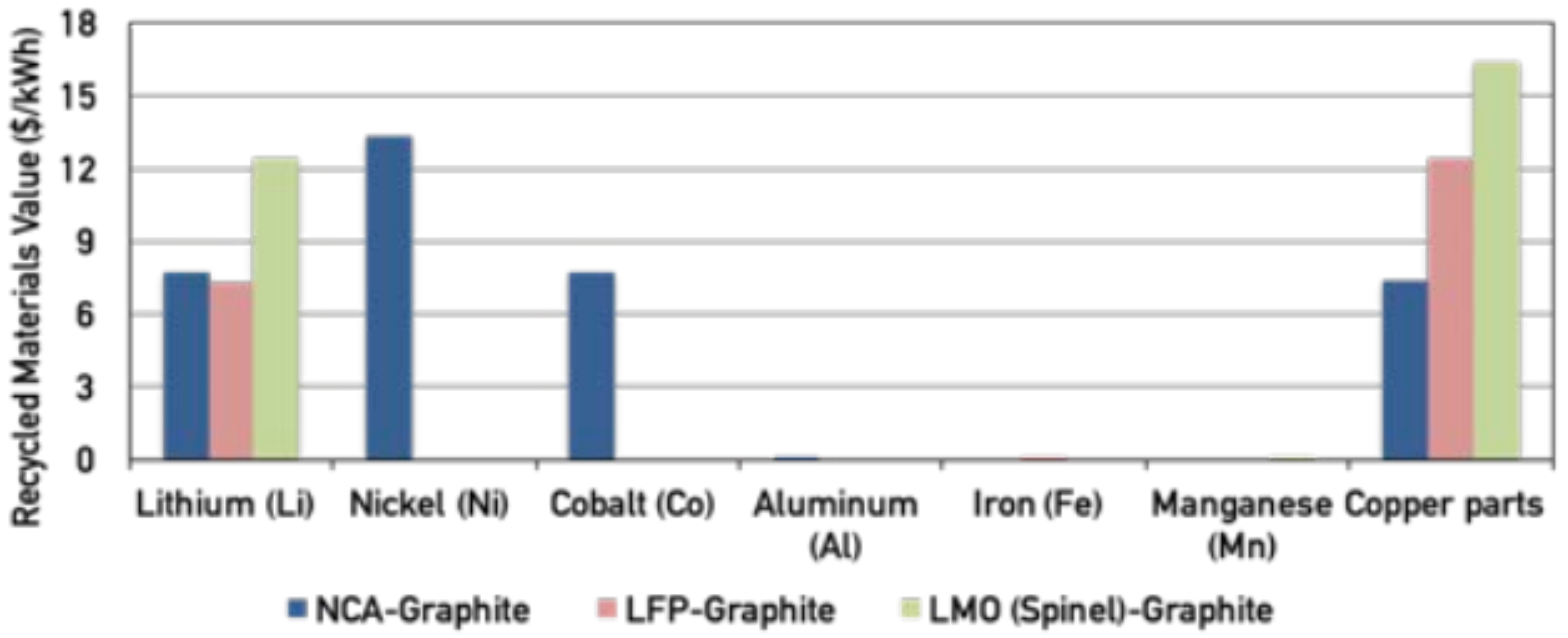
- Lithium-ion batteries (LIBs) have a useful life in EVs of 10-20 years
- Large-scale retirements of LIBs will begin to occur in the next 5-10 years (~3.5 - 30 GWh)
- Disposal of these LIBs represents a major environmental concern
- LIBs are potentially valuable during their second life - a major example is energy storage
- Mineral resourcing is unlikely to limit battery manufacturing in the medium term, but <u>recycling is critical in the long term</u>
- Currently, there is low value in recovered materials, which represents a challenge in raising the capital needed to ramp up recycling infrastructure

Energy Storage from Second-Life EV Batteries



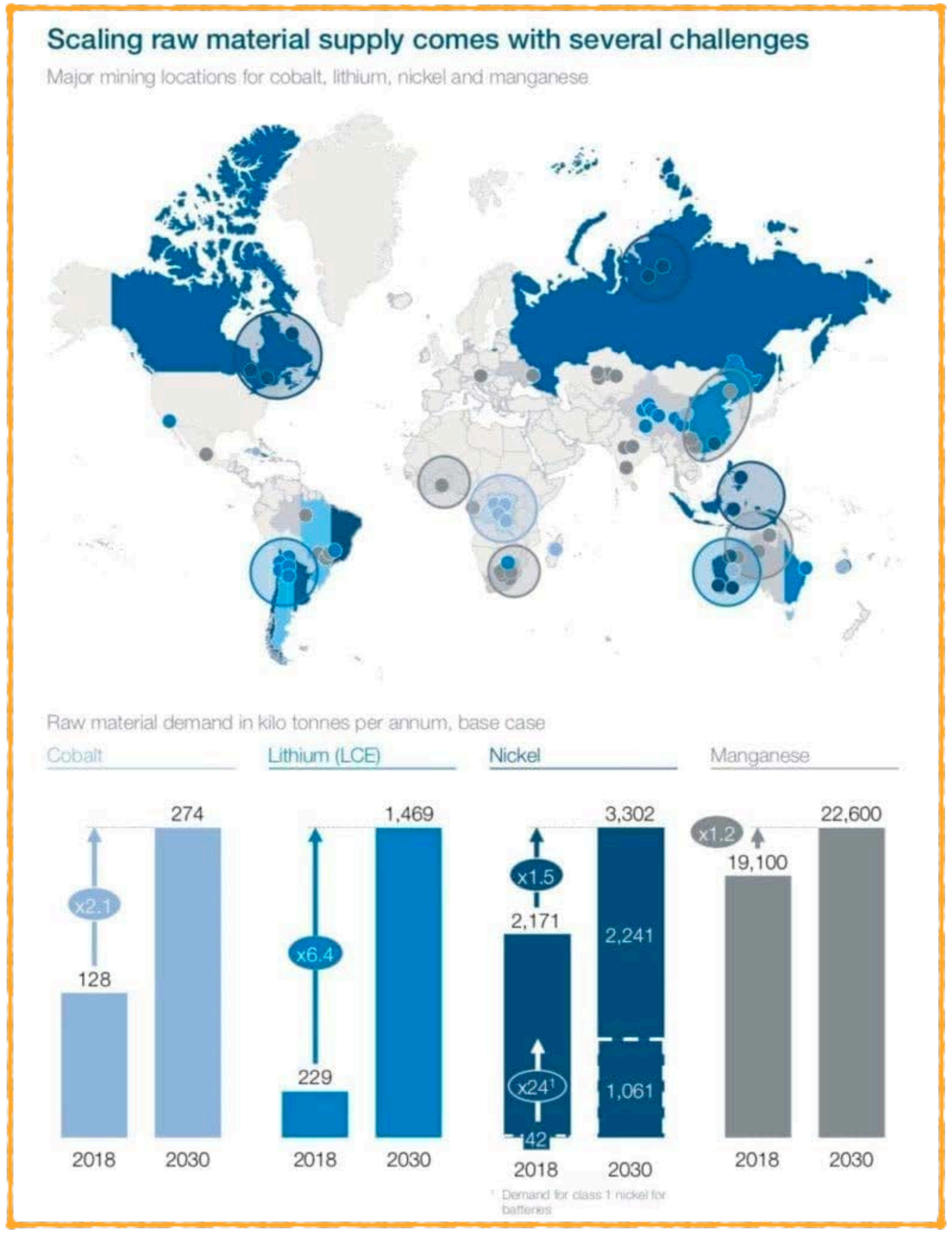
Credit: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/second-life-ev-batteries-the-newest-value-pool-in-energy-storage

Materials Sourcing and Recycling



Retired EV Battery: Economic Analysis Averages		
	Minimum Cost ($/kWh)	Maximum Cost ($/kWh)
Secondary Purchase Cost	$10.00	$100.00
Collection, Testing, Repackaging	$18.00	$140.00
Shipment to Recycling Market	$1.70	$11.26
Recycling	$16.79	$74.29
Sale of Raw Material	$19.60	$36.15

Credit: Ambrose, H., Gershenson, D., Gershenson, A., & Kammen, D. (2014). Driving rural energy access: a secondlife application for electric-vehicle batteries. Environmental Research Letters, 9(9), 094004

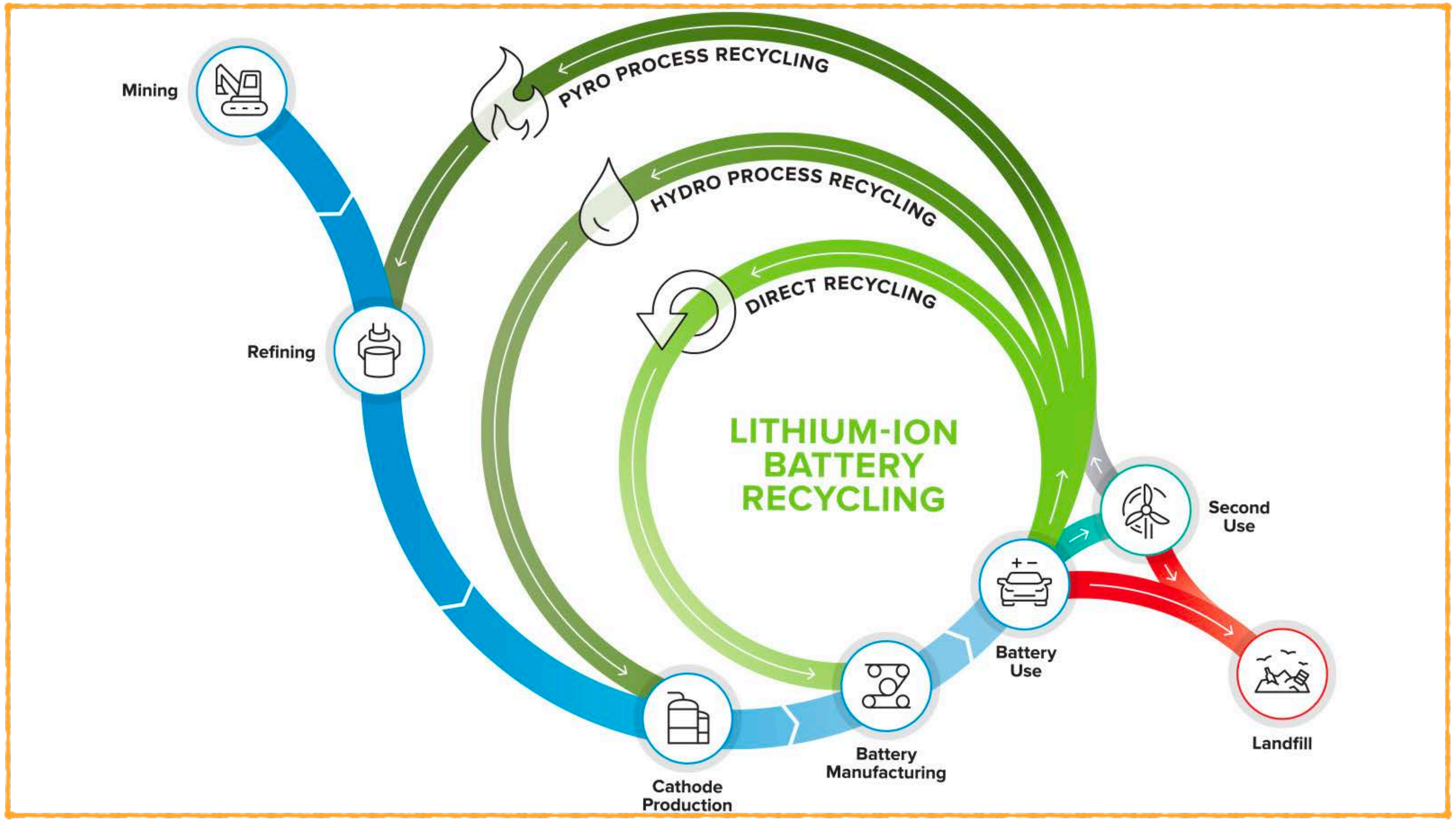


Credit: https://www.anl.gov/article/doe-launches-its-first-lithiumion-battery-recycling-rd-center-recell

Challenges - Recycling

- Design for recycling - many different battery designs
- Safety and liability concerns - consumers, workers, fires
- Economics - who pays for what and when? Is it even economically viable to recycle?
- Regulations - is it a waste? Is it a hazardous waste? Do I need a permit to recycle?
- Nascent industry, with rapidly evolving technology, different recycling technologies have pros and cons

Recycling Processes



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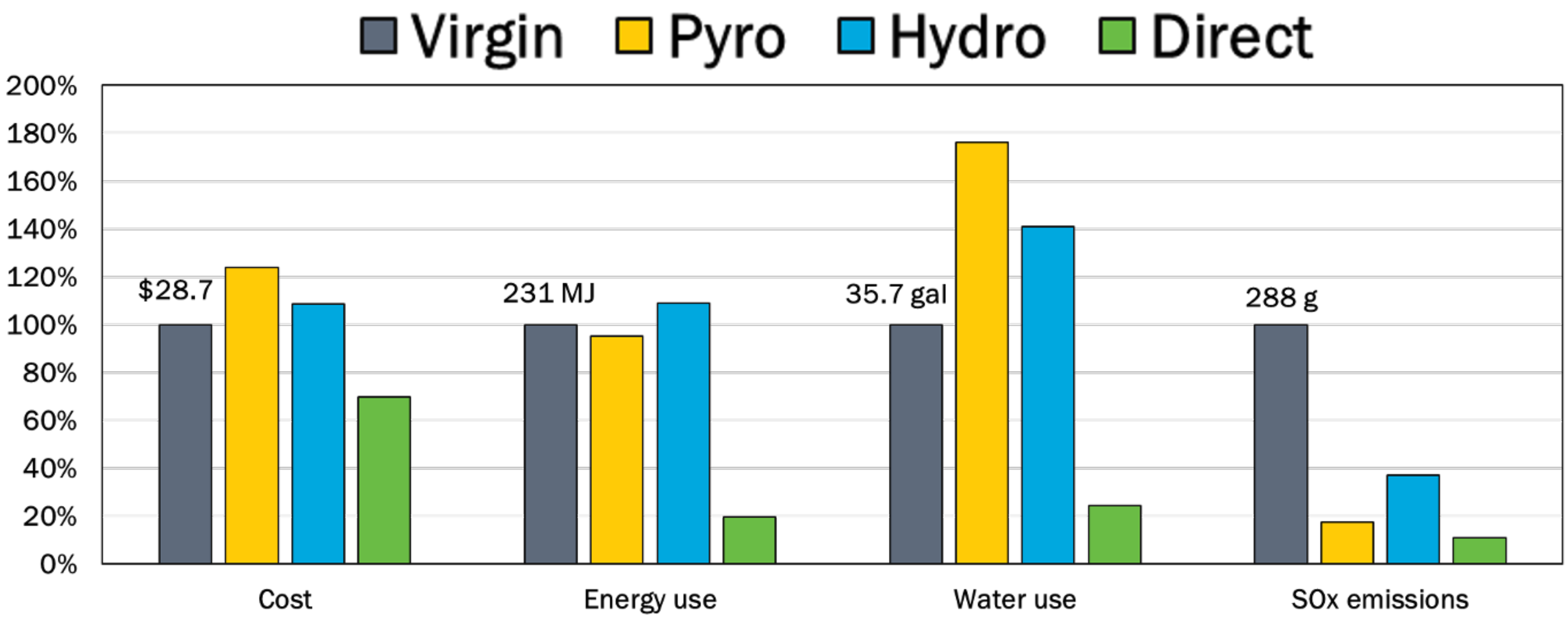
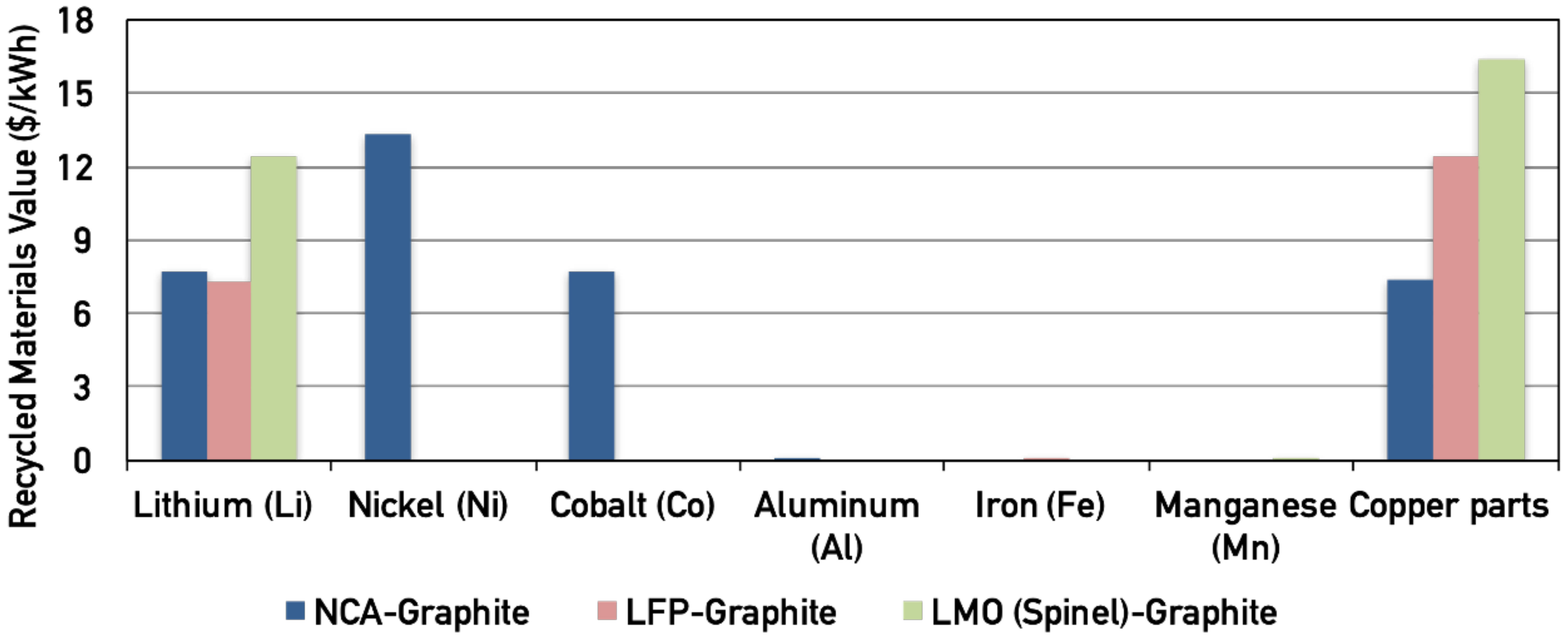
Recycling Processes - Costs



Recovery Costs - Is It Worth It?



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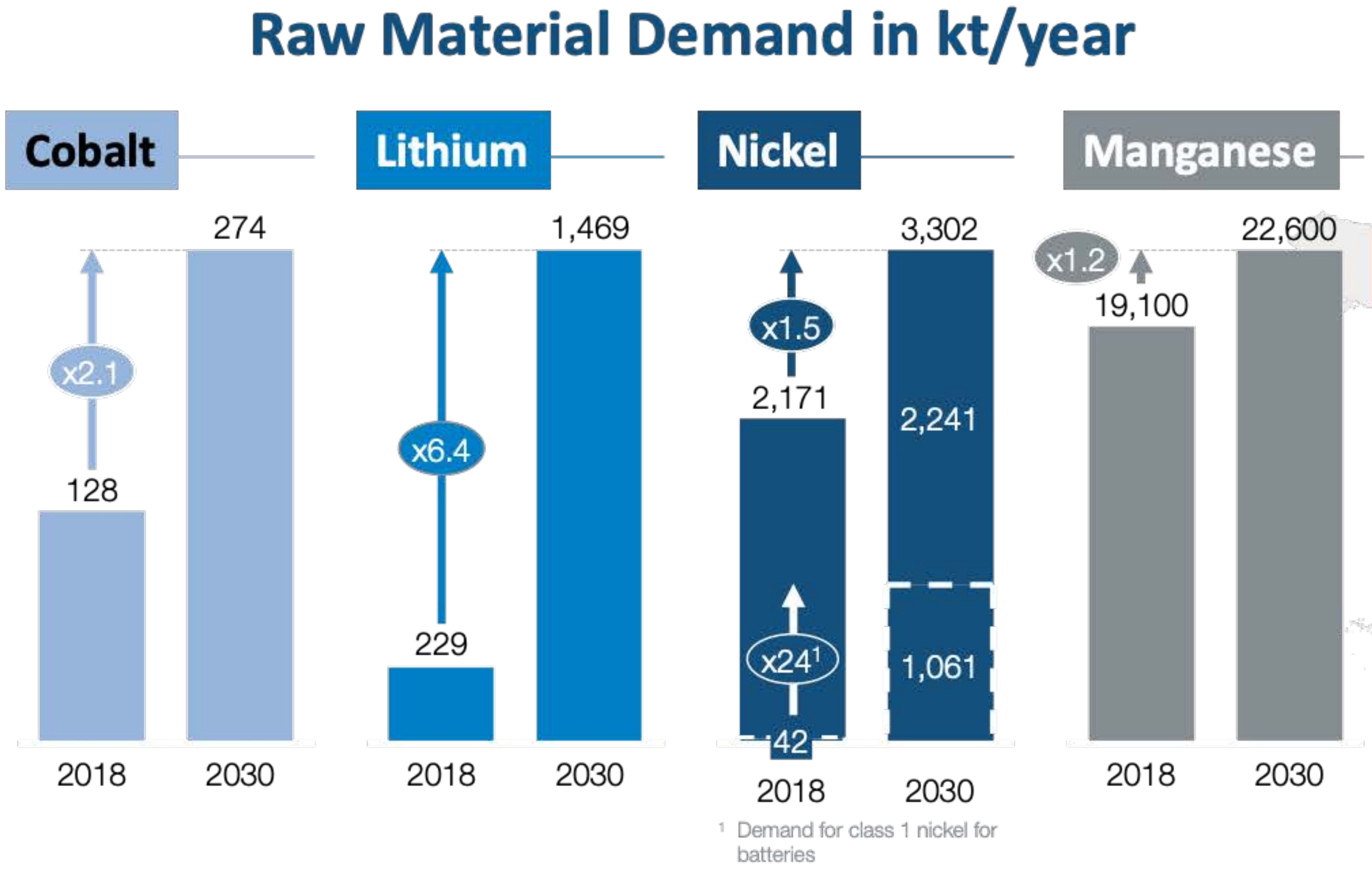
Challenges - Repurposing

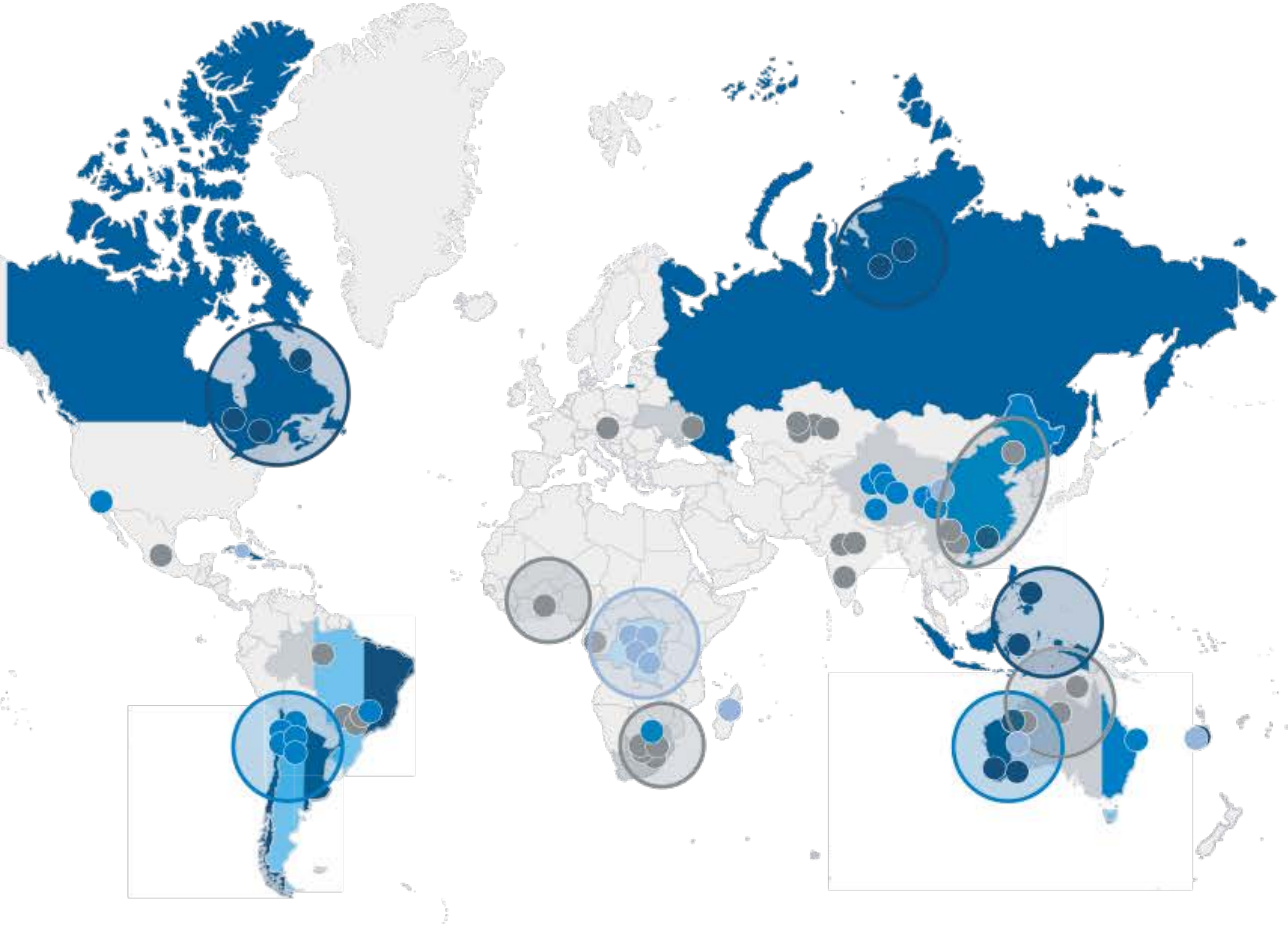
- Safety concerns
- Battery health
- Testing standards
- Prevention of “hobbyist” repurposing
- Battery tracking

Challenges - Manufacturing

- There aren't any technical challenges to battery manufacturing
- Environmental impact
- Need for use of virgin materials
- Supply chain concerns
- Changing technology/chemistries

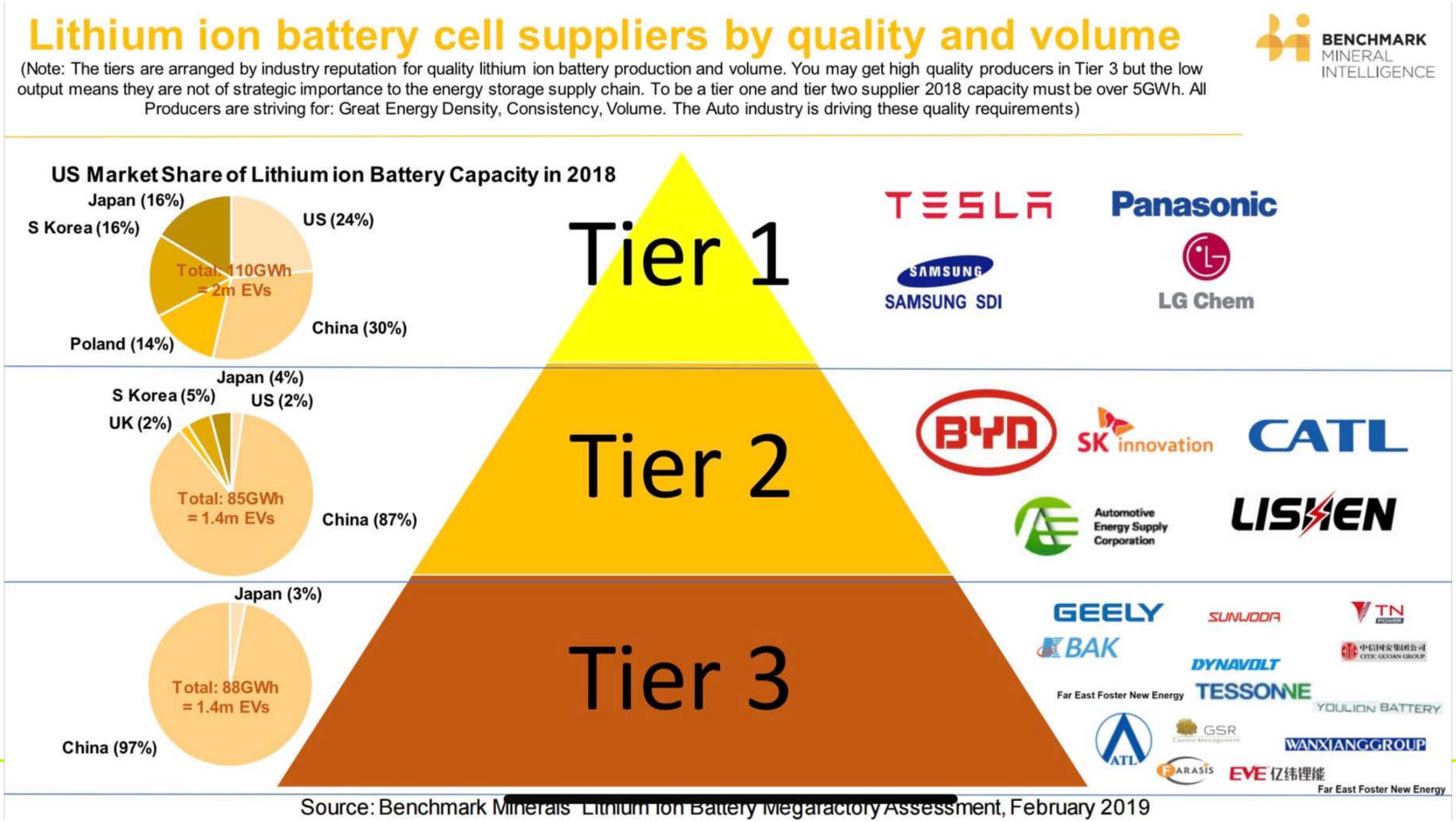
Supply Risks





Credit: Global Battery Alliance

Manufacturing Location



Concepts

- Environmental Protection
- Logistics, Infrastructure, Safety
- Battery Reuse
- Cost-Effective Recycling
- Supply Chain Considerations

Ways To Get Involved

- Webpage - Prior Meeting Materials, Minutes, and Recordings:
  - https://calepa.ca.gov/climate/lithium-ion-car-battery-recycling-advisory-group/
- Listserv - Upcoming Meetings and Announcements:
  - https://calepa.ca.gov/calepa-listservs/subscribe-to-the-lithium-ion-car-battery-recycling-advisory-group/
- Have Further Questions or are Interested in Presenting to the Advisory Group?
  - Direct Contact: mohammed.omer@dtsc.ca.gov

Acknowledgments

- University of California, Davis Lithium-ion Battery Lifecycle Assessment Group:
  - Hanjiro Ambrose, PhD (Co-PI; also Union of Concerned Scientists)
  - Alissa Kendall, PhD (Co-PI)
  - Meg Slattery, Jessica Dunn, Peter Benoliel (PhD Students)
  - Tobiah Steckel (MS Student)

Questions?